Chapter III
Background Information on Methodologies Used In Screen Reclamation Risk, Performance and Cost Evaluation

This chapter is intended to serve as a reference section for the CTSA document and contains details of data collection and methodologies used in the CTSA risk assessment, performance demonstration and cost evaluation. The methodologies and assumptions underlying the evaluations in Chapter 5 are outlined in this chapter, including:

- Screen Printing Workplace Practices Questionnaire
- Occupational Exposures (inhalation and dermal)
- Environmental Releases
- Population Exposure Assessments
- Risk Assessments
- Performance Evaluations
- Cost Estimates

Overview of Data from the Screen Printing Industry Used in Risk Assessment

In August and September 1993, screen printers were surveyed on the workplace practices associated with the screen cleaning/reclamation process. The survey tool was the "Workplace Practices Questionnaire for Screen Printers" (Appendix B), developed by the Screen Printing Association International (SPAI), the University of Tennessee Center for Clean Products and Clean Technologies and staff of the EPA Design for the Environment Program. The survey was developed to characterize typical screen printing facilities and workplace practices associated with the screen cleaning/reclamation process. This information was needed to estimate the amounts and types of environmental releases from the screen cleaning/reclamation process and to estimate exposure from the process. The results were also used to help identify pollution prevention opportunities for screen printers.

SPAI distributed the workplace practices questionnaire to approximately 300 printers, focusing on printers with 20 or fewer employees. Respondents mailed completed questionnaires to SPAI, which sent them to the University of Tennessee Center for Clean Products and Clean Technologies, where they were entered into a data base using FOXPRO software. The University of Tennessee, under a research grant from the EPA Office of Pollution Prevention and Toxics, developed a summary of responses to the questionnaire. Respondents to the survey were guaranteed anonymity and their identities withheld from the computerized database provided to EPA and from the summary of results.

All facilities that received the questionnaire were asked to respond to pages one, two and 11 of the questionnaire, which included a business profile, major products produced, general facility information, equipment and materials use, and pollution prevention opportunities for screen printers. Only screen printers who used solvent or UV-based inks printed on plastic/vinyl substrates were asked to respond to the remainder of the questionnaire.

Appendix C presents the summary of responses to the questionnaire. A total of 115 screen printers responded to the questionnaire, which represents an approximate 38 percent response rate. Representatives from SPAI and the screen printers who participated in the survey should be congratulated for this exceptionally high response rate to a direct mail questionnaire. Of the total, 107 respondents were screen printers who primarily use solvent or UV-based inks printed on plastic/vinyl substrates.

Environmental Releases and Occupational Exposure Assessment

Specific quantities for environmental releases and occupational exposure to chemicals can be determined for a particular system used in screen reclamation. This summary provides an overview of the releases and exposure and methodology used in determining the releases and exposure for the traditional ink remover, emulsion remover, and haze remover products.

While the greatest environmental releases and occupational exposure occur during the actual process of screen reclamation, releases and exposure also occur from volatilization from open containers, transfer operations, sampling operations, and waste rags. Air releases and the inhalation exposures occur as a result of volatilization during these operations. Releases to air occur by volatilization of chemicals from open containers, from the surface of the screen as it is being cleaned, and from rags used in the cleaning process. Estimation of releases to land and water is based on a mass balance relationship. Dermal exposures can also be estimated based on operations, formulation concentrations, and established dermal exposure models.[1]

It is assumed that workers perform the following activities during each step of the screen reclamation process. Some of these steps are not necessary or are altered for certain methods assessed here. See Figure I-2 for an outline of the steps involved in each method.

<u>Step 1. Ink removal</u>

- Open 55-gallon drum of ink remover
- Pour ink remover into 5-gallon pail
- Dip rag or brush into pail
- Remove ink from screen
- Toss rag into laundry pile
- Drum waste ink for disposal

<u>Step 2. Emulsion removal</u>

- Open container of emulsion remover
- Dip brush into container
- Remove emulsion from screen
- Rinse screen

[1]U.S. EPA. *Dermal Exposure Assessment: Principles and Applications*. Office of Health and Environmental Assessment, Jan. 1992, Document no. EPA/600/8-9/011F.

Step 3. Haze removal

- Open container of haze remover
- Dip brush into container
- Remove haze from screen
- Rinse screen

To support the assessments, numerous sources of information were used in gathering data. Preliminary information was collected from the 11-page Screen Printing Workplace Practices Questionnaire. Meetings with printers to discuss the basic data assumptions used in the assessment were held at Screen Print '93 in New Orleans in October 1993 and at the SPAI Environmental Committee Meeting in January 1994. Information was also verified though facilities participating in the Screen Printing Performance Demonstration from February to May 1994. These operation assumptions and data are presented in Table III-1.

Table III-1
Assumptions and Data from Industry and Trade Groups

Type of Data	Average value	
	Number	Units
Number of employees involved in ink removal	3	employees
Hours per employee per day in ink removal	1	hours
Number of employees in screen reclamation	2	employees
Hours per employee per day in screen reclamation	1.5	hours
Average number of screens cleaned per day	6	screens
Average screen size	2,127	in^2
Size of combined screen reclamation/ink removal area	80	ft^2
Amount of ink remover per screen	8 (traditional) 4 (alternative)	oz
Amount of emulsion remover per screen	3.5	oz
Amount of haze remover per screen	3	oz

[a] Normalized from Workplace Practices Questionnaire to remove printing establishments larger than 20 employees.

Estimation Methodology

In general, in evaluating traditional and alternative screen reclamation systems, it is assumed that all releases to air, land, or water occur via the four scenarios described below. Using this assumption cleaning fluid usage has been partitioned to air, land, and water with concentrations of mass. Volatilization is estimated using a number of established models as documented below. Water and land releases are estimated to be all cleaning fluids not volatilized. The exposure/release scenarios are defined as follows:

- Scenario I. Actual screen cleaning operations. Air releases are due to volatilization of chemicals from the screen surface. Unvolatilized material is assumed to be disposed to land or water. Ink, emulsion, and haze removal for 6 screens a day; each screen is approximately $2100 m^2$.

- Scenario II. Releases to the atmosphere from pouring of 1 oz of material for sampling. This is assumed to take place over 15 minutes each day.

- Scenario III. Releases to the atmosphere from pouring of cleaning mixtures from a 55-gallon drum into a 5 gallon pail.

- Scenario IV. Releases from rags stored in a two-thirds empty drum. The water releases in this case occur in a commercial laundry. The drum is opened to add more rags once per day and to transfer the rags from the storage drum to a laundry. Rags are used only for the ink removal step.

Releases shown in the above scenarios will occur during the use of Reclamation Methods 1,2, and 4 of Exhibit 1-2. In addition to these releases, in Method 3 (SPAI Workshop Process), an ink degradant is applied after the ink remover, followed by a water rinse; a screen degreaser is then applied prior to use of the emulsion remover. For the purposes of this assessment, Method 3 is evaluated only in conjunction with system Omicron.

Assumptions for Environmental Releases

The environmental releases model prepared for this report assumes that releases to air equal the total airborne concentration of chemicals from:

- volatilization of solvents from screens
- emissions from transfer operations
- emissions from sampling operations
- volatilization from waste dirty rags

The following assumptions and sources of information were used in the model:

- typical airborne concentrations

- typical ventilation rates

- emission factors from EPA (AP-42) (an EPA compendium of emission factors from the Office of Air)

- formulation data and physical properties

- average amounts of ink, haze, and emulsion remover used per site-day of 36 ounces, 21 ounces, and 18 ounces

The model addresses releases to three media: air, water, and land. Releases to air result from volatilization from the screens during cleaning, and fluid sampling and transfers. Releases for all systems studied were associated with ink removal, emulsion removal, and haze removal.

Water releases result primarily from the emulsion removal phase which is typically a rinse step using a water and sodium hypochlorite or sodium periodate solution for the traditional systems, and a water and sodium periodate solution for the alternative systems. The emulsion removal phase may also generate a contaminated rinsewater. In either phase, waste water results from screen rinsing and the spray or rag application of haze and emulsion removers.

Off-site releases to land result from the cleaning of non-disposable rags and the landfilling of disposable rags. It is assumed that rags are used only to remove the ink. The model assumes that non-disposable rags sent to a laundry contain 0.75 grams of ink remover per 18 rags. This assumption is based on:

- limited data on how much material stays on a damp shop rag with mineral spirits
- the average number of rags used to remove ink per screen (3 per screen)
- the average number of screens cleaned per day (6 screens)

The model assumes weekly laundering of non-disposable shop rags and 250 days of use per year. Similarly, rags sent to a landfill are assumed to contain 0.75 grams of ink remover per 18 rags.

For Systems Omicron and Beta, which have ink remover products that are water-miscible, it was assumed that nonlaunderable rags were used and the discharge to water occurred at the screen printing facility. This assumption was made given that a water rinse is used with these products in removing ink.

For aqueous solutions, the density of all components is assumed equal to 1 g/cm^3. For nonaqueous solutions, ideal solution behavior is assumed and the density of each component is used to find the amount of the component in 4 ounces of ink remover. (See Appendix D for a further explanation).

Assumptions for Occupational Exposure

In order to estimate occupational exposure to chemicals during the screen cleaning process, an inhalation model and a dermal exposure model was developed. The assumptions underlying each model are described below.

Inhalation Model

The inhalation model used in the CTSA is a mass balance model. It assumes that the amount of a chemical in a room equals the amount leaving the room minus any generated in the room. The model is valid for estimating the displacement of vapors from containers, and the volatilization of liquids from open surfaces. Assumptions include:

- incoming room air is contaminant-free

- generation and ventilation rates are constant over time

- room air and ventilation air mix ideally

- Raoult's law is valid (i.e., the volatilization and interaction of vapors)

- ideal gas law applies (i.e., the interaction of vapors)

- inhaled doses of each chemical were based on "typical case" ventilation parameters, since these seem to give the best fit to the highest observed values (see below). Actual ventilation conditions are unknown.

- median values were used for the composition; worst case evaluation for air releases would include the most volatile compound at its maximum concentration.

We used the following assumptions for the frequency and duration of inhalation exposure for ink, emulsion, and haze removal:

- 6 screens cleaned per day
- 1 to 3 workers per site
- 3 hours per day exposure total
- 250 days per year

The four scenarios described on page III-4 were modelled for assessing inhalation exposure. Inhalation exposures occur as a result of volatilization during these scenarios. The model assumes that shop workers do not wear respirators in any of the four scenarios.

Dermal Model

Dermal exposure is caused by contact with the material. Contact with the material includes touching damp rags, dipping hand(s) into a pail of ink remover, and manually applying the brush or rag to the screen to loosen the ink. Two scenarios, routine contact with two hands and routine immersion with two hands, were modelled for assessing dermal exposure. Routine contact occurs from touching rags and manually applying the brush or rag to the screen. Routine immersion occurs from dipping hand(s) into a pail or ink, haze, or emulsion remover.

Dermal contact models from the CEB handbook (CEB, 1991) were used by adjusting the concentration of the chemical in the mixture. Dermal exposure assumes no gloves or barrier creams will be used. Although exposure was estimated for the emulsion removers or haze removers containing sodium hypochlorite or sodium hydroxide, it is usually expected that use of these chemicals would result in negligible exposure given that use of these solutions without gloves causes irritation and corrosivity effects.

Overview of Methodology

CEB (Chemical Engineering Branch) models the evaporation of chemicals from open surfaces, such as the surface of a screen, using the following model:

$$G = \frac{0.02MP}{RT}\sqrt{\frac{D_{ab}v}{\pi z}} \qquad (1)$$

where

G	=	Volatilization rate, $g.m^{-2}.s^{-1}$
M	=	Molecular weight, $g.mol^{-1}$
P	=	Vapor pressure, mm Hg
R	=	Gas constant, 0.0624 $mmHg.m^3.mol^{-1}.K^{-1}$
T	=	Temperature, K
D_{ab}	=	Diffusivity, $cm^2.s^{-1}$
v_z	=	Air velocity, $m.s^{-1}$
z	=	Distance along pool surface, m

The air velocity is assumed to be v_z = 100 $ft.min^{-1}$. Since D_{ab} is not available for many of the chemicals of interest to CEB, the following estimation equation is used:

$$D_{ab} = \frac{4.09\times10^{-5}T^{1.9}(1/29+1/M)^{0.5}M^{-0.33}}{P_t} \qquad (2)$$

where

D_{ab}	=	Diffusion coefficient in air, $cm^2.sec^{-1}$
T	=	Temperature, K
M	=	Molecular weight, $g.mol^{-1}$
P_t	=	Total pressure, atm

This equation is based on kinetic theory and generally gives values of D_{ab} that agree closely with experimental data. The value of G computed from eqs (1) and (2) above is used in the following mass balance expression to compute the airborne concentration in the breathing zone:

$$C_v = \frac{1.7\times10^{5}TGA}{MQk} \qquad (3)$$

where

C_v	=	Airborne concentration, ppm
T	=	Ambient temperature, K
G	=	Vapor generation rate, $g.m^{-2}.sec^{-1}$
M	=	Molecular weight, $g.mol^{-1}$
A	=	Area of surface, m^2
Q	=	Ventilation rate, $ft^3.min^{-1}$
k	=	Mixing factor, dimensionless

The mixing factor accounts for slow and incomplete mixing of ventilation air with room air. CEB sets this factor to 0.5 for the typical case and 0.1 for the worst case. CEB commonly uses values of the ventilation rate Q from 500 $ft^3.min^{-1}$ to 3,500 $ft^3.min^{-1}$. An effective ventilation rate of 250 ft^3/min was used, which was equal to the mixing factor of 0.5 multiplied by the lowest ventilation rate (500 ft^3/min). The value of C_v from equation (3) is converted to mass/volume units as follows:

$$C_m = C_v \frac{M}{V_m} \qquad \textbf{(4)}$$

where

C_m	=	Airborne concentration, mg.m^{-3}
C_v	=	Airborne concentration, ppm
M	=	Molecular weight, g.mol^{-1}
V_m	=	Molar volume of an ideal gas, l.mol^{-1}

At 25 °C, V_m has the value 24.45 l.mol^{-1}. Since a worker can be assumed to breathe about 1.25 m^3 of air per hour, it is a straightforward matter to compute inhalation exposure once C_m has been determined. Equations (3) and (4) can be combined to yield the following, given the "typical case" choice of ventilation parameters:

$$I = 0.48GAt \qquad \textbf{(5)}$$

where

I	=	Total amount inhaled, mg.day^{-1}
G	=	Vapor generation rate, g.m^{-2}.s^{-1}
A	=	Area of surface, m^2
t	=	Duration of exposure, s

The advantage of equation (5) is that the quantity *GAt* is often known beforehand, since it is equal to the total amount of the chemical released to the atmosphere. It is also useful when computing the total dose due to a sudden release of material, such as occurs when a container is opened. In this case, it is difficult to ascertain the duration of exposure, but it is a simple matter to estimate the amount of vapor in the container's headspace.

Example 1. *Estimate the vapor generation rate and worker exposure during removal of ink from a printing screen using 100 percent toluene. The worker cleans screens for 1 hour each day in a room with a ventilation rate of 3,000 ft^3.min^{-1}. The screen area is 2,217 in^2. Assume a mixing factor of k = 0.5.*

Toluene has the following physical properties:

Molecular weight:	92.14 g.mol^{-1}
Vapor pressure:	28 mmHg at 25 °C
Diffusion coefficient:	0.076 cm^2.sec^{-1}

Using these values in equation (1) gives:

Generation rate G:	0.28 g.s^{-1}.m^{-2}
Airborne concentration:	141 ppm (C_v)
	534 mg.m^{-3} (C_m)
Exposure over 1 hour:	667 mg

If the CEB worst-case parameters are used in equation (2), i.e., a mixing factor of k = 0.1 and a ventilation rate of 500 ft^3.min^{-1}, then the estimated airborne concentration is C_v = 4,216 ppm. Exposures and volatilization rates are calculated by multiplying the pure-component values from Exhibit 4 by the mole fraction of that component in the liquid phase. A typical screen has an area of 2127 in^2 = 1.37 m^2. Each worker cleans screens for 1 hour per day. Amounts released should be checked against amount used to ensure mass balance.

Example 2. *If a worker cleans 6 screens using 8 oz/screen of mineral spirits, the amount of spirits used will be:*

6 x 8 x 29.57 fluid oz/cc x 0.78 g/cc = 1107 g

The amount volatilized will be:

$0.01087\ g.m^{-2}.s^{-1} \times 3600\ s \times 1.37\ m^2 = 53\ g$

Thus, the amount volatilized is not limited by the amount used. For the case of the traditional haze remover, however, volatilization is limited by the amount used. If 3 oz of haze remover containing 30 wt percent (32 volume percent or 21 mole percent) acetone is used per screen, the total amount available is:

6 x 3 x 0.32 x 29.57 fluid oz/cc x 0.79 = 133 g

The amount that would volatilize over 1 hour is:

1.49 x 1.37 x 3600 s = 7,350 g

Uncertainties

Occupational Exposure: Uncertainties

Determining occupational exposure levels associated with screen cleaning requires making assumptions about the cleaning process, the workplace environment, health and safety practices, and waste management practices. This section describes the uncertainties involved in assessing occupational exposure for screen cleaning. It also explains the assumptions underlying the exposure assessment model developed for the CTSA.

EPA has published Guidelines for Exposure Assessment in the Federal Register. These are guidelines for the basic terminology and principles by which the Agency is to conduct exposure assessments. There are several important issues relevant to this assessment. If the methodology is one which allows the assessor to in some way quantify the spectrum of exposure, then the assessor should assess typical exposures, as well as high end exposures or bounding exposures. Typical exposures refer to exactly that, how much the typical person is exposed to the particular substance in question. High end refers to a person exposed to amounts higher than 90 percent of the people (or ecological species of interest) exposed to the substance. Bounding estimates are judgements assuming that no one will be exposed to amounts higher than that calculated amount. However, in many cases, all we can do is give a picture of what the exposure would be under a given set of circumstances, without characterizing the probability of these circumstances actually occurring. These are called "What if" scenarios. They do not try to judge where on the exposure scale the estimate actually falls. All of the exposure assessments fall into the "What if" category for this assessment.

Although the screen cleaning process is relatively straightforward, occupational exposure levels will differ in actual shop environments because of many variables such as variations in:

- toxicity of the chemicals used
- amount of chemicals applied
- how the chemicals are applied
- compliance with health and safety and waste management procedures
- equipment operating time
- ventilation conditions and shop lay-out
- temperature conditions (ambient and solvent)

All of these variables will influence the impacts of chemicals used in the screen cleaning process on shop workers. Based on studies of screen printing operations conducted by the National Institute for Occupational Safety and Health (NIOSH), it appears that many of the small to medium sized operations do not follow health and safety precautions.[2] Specifically, workers were observed performing screen reclamation without protective gloves or proper breathing apparatus. Nor did shop workers wear protective aprons to reduce dermal exposure. According to one study, some workers used solvent to wash their arms and hands after completing the screen cleaning process. In another study, rags and paper towels contaminated with solvent were placed in an open trash can. Both of these practices will also increase exposure levels significantly.

There are also differences in how screen printers wash the screens; this affects occupational exposure. Some shops use automated screen washers which blast the screens with solvent or hot water in an enclosed system. Others use a hose in a sink to flush the screens by hand or the cleaner is spread on the screen by hand, and the worker uses a rag or paper towel to wipe down the screen. Exposure levels will differ if individual workers use more (or less) cleaner than specified, and if they allow it to remain on the screen longer than specified.

During research to support this assessment a NIOSH Health Hazard Evaluation (HHE) document on screen washing was located and used to validate exposure estimates. CEB initially estimated occupational exposures by applying the relatively conservative models that are normally used for review of new chemicals. The resulting exposure estimates were high in comparison to actual monitoring data. These data indicated that, after necessary corrections were made, the exposures predicted by the CEB model were within the range of the NIOSH observations, as long as the "typical case" ventilation parameters were chosen. Use of the "worst case" ventilation parameters in the CEB model leads to results that exceed the range of the experimental data by about an order of magnitude. The theoretical basis of the CEB model was investigated and a standard engineering formula for mass transfer in laminar boundary layers was found to provide a closer approximation to the upper end of NIOSH data when used with the same "worst case" ventilation parameters.

Both the CEB model (when used with the "typical case" ventilation parameters) and the boundary-layer approach can provide estimates of inhalation exposures which agree with the experimental data within one order of magnitude or better. It is difficult to obtain better agreement than this without knowing a great deal more about each exposure scenario, such as

[2]Sources: Health Hazard Evaluation Report No. HETA 84-299-1543, (Chicago, IL:Impressions Handprinters). Health Hazard Evaluation Report No. HETA 81-383-1151, (Chicago, IL:Main Post Office).

the details of the screen cleaning process at each site, the solvent temperature, the air temperature, and the ventilation pattern in the screen cleaning area. These items are not routinely recorded by NIOSH investigative teams. A report documenting an alternative volatilization and exposure model based on laminar boundary layers is provided in Appendix E.

Dermal Exposure Model

The dermal exposure model is based on the concentration of material contacting the skin and the surface area contacted. Dermal exposure levels will differ in actual shop environments because of many variables such as variations in:

- type of worker activity
- likelihood or type of contact (i.e., routine or immersion)
- frequency of contact (i.e., routine or incidental)
- potential surface area contacted
- likelihood and effectiveness of protective equipment being used
- amount of chemical remaining on the skin
- evaporation rate of the chemical

In estimating dermal exposure, it was assumed that gloves were not worn. However, assuming that gloves are worn, dermal exposure is assumed to be negligible to none depending on the chemical in question. In situations where the chemical is corrosive (e.g., sodium hypochlorite), dermal exposure to shop workers using gloves is zero. The model assumes that one hand (surface area 650 cm^2) is routinely exposed during the screen cleaning process (1 to 3 mg/cm^2 typically remaining on the skin)[3]

Environmental Releases: Uncertainties

Determining environmental releases associated with screen cleaning requires making assumptions about the cleaning process, the workplace environment, and waste management practices. This section describes the uncertainties involved in assessing environmental releases associated with screen cleaning. It also explains the assumptions underlying the environmental release assessment model developed for the CTSA.

Uncertainties

Uncertainties related to environmental releases overlap with the uncertainties associated with occupational exposure. They include variations in:

- toxicity of the chemicals used
- amount of chemicals applied
- how the chemicals are applied
- compliance with waste management procedures
- equipment operating time
- ventilation conditions and shop lay-out
- temperature conditions (ambient and solvent)

[3] Source: U.S. Environmental Protection Agency, *Chemical Engineering Branch Manual for the Preparation of Engineering Assessments*, (February 28, 1991), p. 4-36.

Release Amounts vs. Occupational Exposures

Air releases were computed in two different ways, depending on the particular scenario under consideration. For Scenario I (evaporation from a screen) and Scenario II (evaporation during sampling), the equations used for computing the total mass of material volatilized can be condensed into the following expression:

$$GAt = \frac{8.24\times10^{-8} M^{0.835} P\left(\frac{1}{29}+\frac{1}{M}\right)^{0.25} v_z^{0.5} At}{T^{0.05} z^{0.5} P_t^{0.5}} \tag{6}$$

where:

GAt	=	Mass released (= flux x area x time)
M	=	Molecular weight ($g.mol^{-1}$)
P	=	Vapor pressure (mmHg)
v_z	=	Air velocity ($ft.min^{-1}$)
A	=	Area of surface (cm^2)
t	=	Duration of release (s)
T	=	Air temperature (K)
z	=	Length of surface (cm)
P_t	=	Total pressure (atm)

For all cases of interest here, the temperature T, total pressure P_t, and air velocity v_z are assigned fixed values. These are 298 K, 1 atmosphere, and 100 $ft.min^{-1}$, respectively. In addition, the surface is taken to be square, so that $z = A^{0.5}$. Thus, the mass of material released has the following dependencies:

$$GAt \propto M^{0.835}\left(\frac{1}{29}+\frac{1}{M}\right)^{0.25} \tag{7}$$

$$GAt \propto P \tag{8}$$

$$QAt \propto A^{0.75} \tag{9}$$

For Scenario III (releases from pouring) and Scenario IV (releases from drum of rags), the vapor space of the container was assumed to be saturated. The model used can be represented as:

$$QAt = \frac{MPV}{(24.45)(760)} \tag{10}$$

where:

M	=	Molecular weight ($g.mol^{-1}$)

P = Vapor pressure (mmHg)
V = Volume of container (l)

For each scenario, the container volume is fixed, so that:

$$QAt \propto M \tag{11}$$

$$QAt \propto P \tag{12}$$

Releases to water and/or land disposal are computed by a mass balance approach; any chemical not volatilized is assumed to be disposed to one of these two media.

The amount of each chemical inhaled by workers is given by the following expression:

$$I = \frac{719}{Qk} GAt \tag{13}$$

where
I = Inhaled dose (mg.day^{-1})
Q = Ventilation rate (ft^3.min^{-1})
k = Mixing factor (dimensionless)

In this report, Q is fixed at 3,000 ft^3.min^{-1} and k = 0.5. Thus,

$$I = 0.48 GAt \tag{14}$$

Thus, the inhaled dose has the same dependencies as the amount released, no additional variables being introduced.

Based on the above expressions, the amount released to the atmosphere in Scenarios I and II is approximately proportional to $M^{0.835}P$. For Scenario III and IV, the dependence is approximately MP. The vapor pressure is generally lower for compounds with higher molecular weights. An idea of the sensitivity of vapor pressure to molecular weight can be obtained from a molecular model of the liquid state. According to Fowler and Guggenheim (*Statistical Thermodynamics*, Cambridge, 1956), for a liquid whose intermolecular potential energy can be represented by the Lennard-Jones function:

$$U(r) = 4\epsilon[(\frac{\sigma}{r})^6 - (\frac{\sigma}{r})^{12}] \tag{15}$$

the vapor pressure can be estimated to be:

$$p = 1158 \frac{\epsilon}{\sigma^3} e^{-8.136(\epsilon/kT)} \tag{16}$$

As noted in the development of an expression for D_{ab}, the diffusivity, in Appendix K of the CEB Manual, the quantities ϵ and σ can be roughly correlated with molecular weight. When these parameters are regressed against experimental data for C_1-C_9 and substituted into the expression for vapor pressure, a relationship of the following form is observed:

$$p \propto M^{0.23} e^{-M^{0.51}} \tag{17}$$

Somewhat different dependencies will be found with different sets of experimental data, but all of the resulting expressions will show that vapor pressure falls off rapidly with molecular weight within a homologous series of compounds. Thus, the amount of chemical volatilized and the resulting inhaled dose will be approximately proportional to

$$M^{0.69} e^{-M^{0.51}} \tag{18}$$

Population Exposure Assessment for Screen Reclamation Processes

The purpose of a general population exposure assessment is to account for amounts of chemicals with which people who are not directly involved in the screen printing process may be in contact. There are several ways that the general population may be exposed to substances used in the screen reclamation process. People may breathe the air containing vapors which have been carried away by air currents from a screen printing facility. The vapors would be environmental releases stemming from evaporation of products at the screen printing facility. People may drink water which contains residues from the reclamation products, which can originate with the facility discharging the products down the drain. People may also drink well water that contains contaminants which have migrated from a landfill where wastes are disposed. The amount which a person may come in contact with varies with how far away they are located from the facility, how many of the different routes of contact they actually have (such as drinking, breathing, touching), how long the chemical has been in the environment and how the chemical moves through the environment. The amounts also depend on such environmental conditions as the weather or the amount of water that is flowing in the receiving stream or river where the facility's discharges go.

EPA has published Guidelines for Exposure Assessment in the Federal Register. These are guidelines for the basic terminology and principles by which the Agency is to conduct exposure assessments. There are several important issues relevant to this assessment. If the methodology is one which allows the assessor to in some way quantify the spectrum of exposure, then the assessor should assess typical exposures, as well as high end exposures or bounding exposures. Typical exposures refer to exactly that, how much the typical person is exposed to the particular substance in question. High end refers to a person exposed to amounts higher than 90 percent of the people (or ecological species of interest) exposed to the substance. Bounding estimates are judgements assuming that no one will be exposed to amounts higher than that calculated amount. However, in many cases, all we can do is give a picture of what the exposure would be under a given set of circumstances, without characterizing the probability of these circumstances actually occurring. These are called "What if" scenarios. They do not try to judge where on the exposure scale the estimate actually falls. All of the exposure assessments fall into the "What if" category for this assessment.

The fate of the chemical in the environment is how we refer to the breakdown (transformation) and mobility of the chemical through air, water and land. There is a different chemical fate for release through a waste water treatment facility as opposed to an air release or a landfill release. There are also different processes by which degradation may occur. For example, in air, a chemical may be broken down by sunlight (by either direct photolysis or photooxidation) or by reaction with water in the atmosphere (hydrolysis). In water and soil, an important degradation process is biodegradation, where the substance may be decomposed by bacteria and other biota in the environment. Each of these processes will have its own rate (speed) at which it occurs, and this may vary with the concentration of the chemical in the system. Often the way we present the fate for a chemical is by giving a half-life value. This term simply means the amount of time it takes for one-half of the substance initially present to be lost by degradation. There are other ways to present fate. If we are interested in how much of a chemical is removed from water during its trip through a waste water treatment facility (such as a POTW - Publicly Owned Treatment Works), we will give a removal amount, usually in percent. There are summaries in Chapter 2 of the chemical fate of all of the chemicals identified as being used in screen reclamation products.

There are two perspectives to address when handling exposure concerns for any commercial process. The first is best described as a local point of view, i.e., a single facility in normal operation will have certain releases which affect a specific area and specific local population. Since we do not have information for each screen printing facility, we use a "model facility" approach to calculate typical releases and environmental concentrations. This will not allow us to specify the number of people around the facility, because the population varies considerably depending on the location of the screen printing facility. The other perspective is to view the overall impact, i.e., what is the impact of all of the printing facilities for the general population. While one facility may not be releasing very much of any given chemical, the cumulative effect of all of the printers in an area could be serious.

For this assessment, we have tried to present a view of the local concerns by presenting exposures for a standard set of conditions, by which we are trying to simulate a single facility for all of the methods and systems. The overall perspective is presented only for the traditional systems, which are the systems which are considered to already be in common use. It was felt that it would far too hypothetical to do an overall perspective for the alternative formulations since we do not have a basis for predicting how many screen printers might use any given formulation.

The effects of a chemical may be a short-term (acute) effect, such as the effect a poison would have on the body, or it could be long-term, such as a carcinogen. For long-term (chronic) effects, it is most helpful to have average, or typical, exposures, since the effect will vary with the cumulative exposure. For acute effects, a peak exposure estimate would be more helpful. This can then be compared to levels at which the chemical is known to give immediate health problems. In general for this assessment, average concentrations are calculated.

Overview by Media

Air

Releases to air are from evaporation of chemicals during the process. This may be from allowing screens to dry during reclamation, or from rags or open drums of chemicals located around the facility. These vapors are then carried and mixed with outside air. The air concentration will depend on weather conditions. Stagnant conditions will not move vapors away quickly, so local concentrations will be higher than the concentrations of the chemical farther from the plant. There is the potential that everyone outside the facility could be affected. The chemical concentrations will decrease with distance, but the number of people may increase with distance, depending on the location of the screen printing facility. Usually the exposure assessor will use a computer program to determine the number of people around a known facility by using census data. Since the locations of all the screen printing facilities across the country are not known to us, we use the model facility approach, and do not count population for the model facility.

For our model facility, we assume a building height of three meters, and a width of 10 meters. This is a building approximately the size of a garage. We then pick sample weather conditions, usually from San Bernardino, to determine what the air concentration of a chemical will be at a set distance from the printing facility. We use San Bernardino because the weather conditions there will give the highest average concentrations around the facility of any of the approximately 500 weather stations in the United States. However, none of the average concentrations across the country will be even ten times less than the average concentrations at San Bernardino. If the highest concentration were 10 ug/m^3, then anywhere in the country the concentration would be greater than 1 ug/m^3. We would say that there is less than an order of magnitude difference.

Methodology References

Air Modeling Parameters for ISCLT90

MODEL - Industrial Source Complex, Long Term; US EPA, Office of Air and Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711, version 90, as implemented by the Office of Pollution Prevention and Toxics in the Graphical Exposure Modeling System, GEMS Atmospheric Modeling Subsection.

The following default parameters were used:

- Regulatory default setting for ISCLT.
- Facility location at 34° latitude, 117° longitude
- The Star Station (meteorological) data from the station closest to the point of release, San Bernardino, CA.
- Urban Mode (U3)

- Standard Polar grid, with 3 calculations per segment.
- Single point of release at the facility location.
- Release height of 3 meters for fugitive releases from an area source of 10 meters by 10 meters (100 m^2).

Surface Water

Releases to surface water are those releases discharged through a drain at a screen printing facility that end up going to public sewers or Publicly Owned Treatment Works (POTWs). This discharge is treated before being released, and the effectiveness of the treatment determined, so that the amount actually getting through to the receiving water body can be calculated. The receiving water will dilute the discharge from the POTW, and a stream concentration can be calculated using stream flow information.

We use average stream concentrations to calculate average drinking water consumption. We assume that people actually drink the two liters a day that is recommended for good health. If the chemical is one that will accumulate in animals or plants, we calculate ingestion of the chemical from eating fish.

The other issue for surface water is the effect that a chemical may have on aquatic organisms, from algae to fish. If the food chain is broken in a stream, the consequences are dire. No algae, no fish. A healthy stream with numerous organisms will also have a better ability to handle chemical releases than one whose quality is already compromised. The organisms lower on the food chain, such as algae, tend to have shorter lives, making shorter exposure time periods more critical. Since concentrations will vary with the stream flow, there may be periods of lower flow conditions where the same amount released as on a regular flow situation will cause problems. We use historical stream data to try to predict how often this will happen.

Cumulative releases to the same POTW may be estimated by counting the number of screen printers in an area and distributing the releases across all the POTW's in the area. We have to assume that the releases are for the same products, or very similar products. As for air, this cumulative number is expected to be far more significant than the amount for any single screen printer.

Methodology Reference

Single Site

Concentration = Chemical Loading / Streamflow

In general, the concentration will be in ug/L, and the chemical loading is in grams or kilograms. The streamflow used is the harmonic mean streamflow in Million Liters per Day (MLD) for drinking water concerns, if the location is known. Otherwise, the streamflow will be assumed to be 1000 MLD.

US-Wide Water Releases

The methodology used is outlined in its entirety in a report from VERSAR, Inc for Task I-11, subtask 101, from Contract 68-D3-0013. Copies of this report are available from either VERSAR, Inc or from Sondra Hollister at EPA.

Septic Systems

There appears to be a significant minority of screen printers who do not release water to a waste water treatment plant. These printers are assumed to release to septic systems. The releases of this type are not modeled in this assessment. There are some general guidelines that may be used to determine if there will be exposure to any of the screen reclamation chemicals from septic system seepage. Each chemical will have an estimated potential migration to ground water, which is usually used for landfill assessments. This can be directly applied to septic systems, because the potential to migrate to ground water will be the same. Of course the individual characteristics of the system will determine the actual speed that each chemical travels into the ground water. If the septic system is relatively leaky, and the ground water table is relatively high, the time that a chemical takes to get into the ground water will be shorter than for a septic system which is sealed well and where the ground water table is low.

Landfill

Our usual techniques for estimating exposures from landfill releases are not applicable to printing. For a typical situation, we would assume one facility sending waste to a landfill. For the printing industry, the use of landfills cannot be so simplified. A lack of data limits the determination of exposures. We do not know how many printers are sending what types of wastes to any given landfill. There also is no way to account for a printer sending a portion of their wastes to a hazardous waste handler, and sending another portion to the county landfill, or how many printers will be sending to any given landfill. For these reasons, even though the exposures from landfill releases may be significant, we will not be able to calculate exposures from landfill seepage and migration into ground water. However, we can give the expected fate of the chemical in the landfill -- will the chemical migrate to ground water rapidly, moderately or negligibly.

Background on Risk Assessment for Screen Reclamation Processes

Human Health Risk

Assessment of the human health risks presented by chemical substances includes the following components of analysis:

- **Hazard Identification** is the process of determining whether exposure to a chemical can cause an adverse health effect and whether the adverse health effect is likely to occur in humans.

- **Dose-response Assessment** is the process of defining the relationship between the dose of a chemical received and the incidence of adverse health effects in the exposed population. From the quantitative dose-response relationship, toxicity values are derived that are used in the risk characterization step to estimate the likelihood of adverse effects occurring in humans at different exposure levels.

- **Exposure Assessment** identifies populations exposed to a chemical, describes their composition and size, and presents the types, magnitudes, frequencies, and durations of exposure to the chemical.

- **Risk Characterization** integrates hazard and exposure information into quantitative and qualitative expressions of risk. A risk characterization includes a description of the assumptions, scientific judgments, and uncertainties embodied in the assessment.

Quantitative Expressions of Hazard and Risk

The manner in which estimates of hazard and risk are expressed depends on the nature of the hazard and the types of data upon which the assessment is based. For example, cancer risks are most often expressed as the probability of an individual developing cancer over a lifetime of exposure to the chemical in question. Risk estimates for adverse effects other than cancer are usually expressed as the ratio of a toxicologic potency value to an estimated dose or exposure level. A key distinction between cancer and other toxicologic effects is that most carcinogens are assumed to have no dose threshold; that is, no dose or exposure level can be presumed to be without some risk. Other toxicologic effects are generally assumed to have a dose threshold; that is, a dose or exposure level below which a significant adverse effect is not expected.

Cancer Hazard and Risk

EPA employs a "weight-of-evidence" approach to determine the likelihood that a chemical is a human carcinogen. Each chemical evaluated is placed into one of the five weight-of-evidence categories listed below.

- <u>Group A</u> - human carcinogen

- <u>Group B</u> - probable human carcinogen. B1 indicates limited human evidence; B2 indicates sufficient evidence in animals and inadequate or no evidence in humans.

- <u>Group C</u> - possible human carcinogen

- <u>Group D</u> - not classifiable as to human carcinogenicity

- <u>Group E</u> - evidence of noncarcinogenicity for humans

When the available data are sufficient for quantitation, EPA develops an estimate of the chemical's carcinogenic potency. EPA "slope factors" express carcinogenic potency in terms of the estimated upper-bound incremental lifetime risk per mg/kg average daily dose. "Unit risk" is a similar measure of potency for air or drinking water concentrations and is expressed as risk per ug/m^3 in air or as risk per ug/l in water for continuous lifetime exposures.

Cancer risk is calculated by multiplying the estimated dose or exposure level by the appropriate measure of carcinogenic potency. For example an individual with a lifetime average daily dose of 0.3 mg/kg of a carcinogen with a potency of 0.02/mg/kg/day would experience a lifetime cancer risk of 0.006 from exposure to that chemical. In general, risks from exposures to more than one carcinogen are assumed to be additive, unless other information points toward a different interpretation.

Chronic Health Risks

Because adverse effects other than cancer and gene mutations are generally assumed to have a dose or exposure threshold, a different approach is needed to evaluate toxicologic potency and risk for these "systemic effects." "Systemic toxicity" means an adverse effect on any organ system following absorption and distribution of a toxicant to a site in the body distant from the toxicant's entry point. EPA uses the "Reference Dose" approach to evaluate chronic (long-term) exposures to systemic toxicants. The Reference Dose (RfD) is defined as "an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious effects during a lifetime" and is expressed as a mg/kg/day dose. The RfD is usually based on the most sensitive known effect; that is, the effect that occurs at the lowest dose. EPA calculates a comparable measure of potency for continuous inhalation exposures called a Reference Concentration or RfC, expressed as a mg/m^3 air concentration. Although some RfDs and RfCs are based on actual human data, they are most often calculated from results obtained in chronic or subchronic animal studies. The basic approach for deriving an RfD or RfC involves determining a "no-observed-adverse-effect level (NOAEL)" or "lowest-observed-adverse-effect level(LOAEL)" from an appropriate toxicologic or epidemiologic study and then applying various uncertainty factors and modifying factors to arrive at the RfD/RfC.

RfDs and RfCs can be used to evaluate risks from chronic exposures to systemic toxicants. EPA defines an expression of risk called a "Hazard Quotient" which is the ratio of the estimated chronic dose/exposure level to the RfD/RfC. Hazard Quotient values below unity imply that adverse effects are very unlikely to occur. The greater the Hazard Quotient exceeds unity, the greater is the level of concern. However, it is important to remember that the Hazard Quotient is not a probabilistic statement of risk. A quotient of 0.001 does not mean that there is a one-in-a-thousand chance of the effect occurring. Furthermore, it is important to remember that the level of concern does not necessarily increase linearly as the quotient approaches or exceeds unity because the RfD/RfC does not provide any information about the shape of the dose-response curve.

An expression of risk that can be used when an RfD/RfC is not available is the "Margin-of-Exposure (MOE)." The MOE is the ratio of a NOAEL or LOAEL (preferably from a chronic study) to an estimated dose or exposure level. Very high MOE values such as values greater than 100 for a NOAEL-based MOE or 1000 for a LOAEL-based MOE imply a very low level of concern. As the MOE decreases, the level of concern increases. As with the Hazard Quotient, it is important to remember that the MOE is not a probabilistic statement of risk.

Developmental Toxicity Risks

Because of the many unique elements associated with both the hazard and exposure components of developmental toxicity risk assessment, these risks are treated separately from other systemic toxicity risks.

EPA defines developmental toxicity as adverse effects on the developing organism that may result from exposure prior to conception, during prenatal development, or postnatally to the time of sexual maturation. Adverse developmental effects may be detected at any point in the life span of the organism. The major manifestations of developmental toxicity include: (1) death of the developing organism, (2) structural abnormality, (3) altered growth, and (4) functional deficiency.

There is a possibility that a single exposure may be sufficient to produce adverse developmental effects. Therefore, it is assumed that, in most cases, a single exposure at any of several developmental stages may be sufficient to produce an adverse developmental effect. In the case of intermittent exposures, examination of the peak exposure(s) as well as the average exposure over the time period of exposure is important.

EPA has derived Reference Doses and Reference Concentrations for developmental toxicants in a similar manner to the RfDs and RfCs for other systemic toxicants. The RfD_{DT} or RfC_{DT} is an estimate of a daily exposure to the human population that is assumed to be without appreciable risk of deleterious developmental effects. The use of the subscript DT is intended to distinguish these terms from the more common RfDs and RfCs that refer to chronic exposure situations for other systemic effects.

Developmental toxicity risk can be expressed as a Hazard Quotient (dose or exposure level divided by the RfD_{DT} or RfC_{DT}) or Margin-of-Exposure (NOAEL or LOAEL divided by the dose or exposure level), with careful attention paid to the exposure term, as described above.

NOTE: The closely related area of reproductive toxicity is also an important aspect of systemic toxicity. For purposes of this report, toxicity information on adult male and female reproductive systems will be assessed as part of the chronic toxicity risk.

Assumptions and Uncertainties

Estimated doses assume 100 percent absorption. The actual absorption rate may be significantly lower, especially for dermal exposures to relatively polar compounds. The assessment used the most relevant toxicological potency factor available for the exposure under consideration. In some cases the only potency factor available was derived from a study employing a different route of exposure than the exposure being evaluated. For example, oral RfD values were sometimes used to calculate Hazard Quotients for inhalation and dermal exposures. For the occupational risk assessment, RfC values were converted to units of dose assuming a breathing rate of 20 m^3/day and a body weight of 70 kg. This conversion was done because occupational inhalation exposures were calculated as a daily dose rather than as an average daily concentration. The general population risk estimates compare RfC values directly to average daily concentrations because continuous exposure is assumed for the general population. Most of the Margin-of-Exposure calculations presented in the assessment are based on toxicity data that have not been formally evaluated by the Agency. Simple esters of glycol ethers were assumed to present the same hazards at approximately the same potencies as the corresponding alcohol. The same potency data were used in risk estimates for each alcohol and its corresponding ester unless specific data for each compound were available.

All risk estimates are based on release and exposure values estimated from information on product usage and work practices obtained from industry surveys. No actual measures of chemical release or exposure levels were available.

Certain formulation components are described in the CTSA by their category name, such as propylene glycol series ethers. However, all risk calculations in the CTSA are based on chemical-specific hazard and exposure data. Thus, risk values may appear for some category members but not others because of limitations in available data.

Ecological Risk

The basic elements of ecological risk assessment are similar to those employed in human health risk assessment. This report will address only ecological risks to aquatic species. Quantitative evaluation of aquatic risks involves deriving an "ecotoxicity concern concentration (ECO CC)" for chronic exposures to aquatic species. The ECO CC may be based either on actual toxicologic test data on the subject chemical or on quantitative structure-activity relation analysis of test data on similar chemicals. The ECO CC is typically expressed as a mg/l water concentration. Concentrations below the ECO CC are assumed to present low risk to aquatic species. A notation of "N.E.S." rather than a numeric estimate of the ECO CC indicates that no adverse effects are expected in a saturated solution during the specified exposure period.

For further background on the determination of ecological hazard, see Appendix M.

Background and Methodology for Performance Demonstrations

Background

One purpose of the DfE Printing Project was to collect and disseminate to printers information concerning the performance of several screen reclamation alternatives. This section of the CTSA summarizes performance information collected during laboratory and production run performance demonstrations with alternative screen reclamation products carried out between January and April 1994. Performance data collected includes time spent on ink removal, volume used, and appearance of the screen following each step. Information from the performance demonstrations, taken in conjunction with risk, cost and other information in the CTSA, provides a more complete assessment of product systems than has otherwise been available from one source. DfE participants believe that this information will allow printers to make a number of comparisons that were not previously possible. For example, printers can compare cost, risk and performance between screen reclamation systems currently used and alternative systems as well as across the alternative systems evaluated during the performance demonstrations.

In a joint and collaborative effort, EPA and the Screen Printing Association International (SPAI) organized and conducted the performance demonstrations of 11 screen reclamation product systems and one alternative technology.[4] The DfE project staff contacted all known product manufacturers to request submission of product systems. The industry participants and the internal EPA workgroup decided to request that alternative product systems contain no stratospheric ozone depleting substances and no chlorinated compounds. This is due, in part,

[4]Product systems are whatever combination of specific ink removers, emulsion removers, and haze removers the participating manufacturer submitted or recommended.

to the expectation that impending regulations may effect market availability and use of these substances. The DfE Project Staff did not solicit those products containing chlorinated compounds due to the scheduled phase-out of many of these chemicals under the 1990 Clean Air Act Amendments.

Performance data were collected for each product system in a laboratory setting at the Screen Printing Technical Foundation (SPTF) and also in production runs at 23 volunteer facilities. The performance demonstration protocol was developed by consensus with the involvement of EPA, product manufacturers, and screen printers. The protocol was designed to allow the evaluation of the maximum number of product systems given the resources available to the project. The intent of the SPTF evaluations was to assure that the product systems sent to printers would provide an acceptable level of performance. This screening level evaluation also provided another set of observations to compare with in-facility demonstration results. In-facility testing was undertaken at the request of printers participating in the DfE project so that product systems would be evaluated during production runs at printing facilities. It should be noted that the performance demonstrations are not rigorous scientific investigations. Instead, the performance information in Chapter 5 documents the printers' experiences with and opinions of these products as they were used in production runs at their facilities.

Methodology

Performance evaluations were conducted in two distinct phases of the project. SPTF evaluated products under very controlled and consistent conditions. Volunteer printing facilities nationwide collected much of the same information, but did so under more variable conditions during production. The methodologies for data collection at SPTF and at the printing facilities are outlined below.

SPTF Evaluations

At SPTF, each product system was tested on three imaged screens; one with solvent-based ink, one with UV-cured ink and one with water-based ink. One of the most important aspects of the SPTF methodology is that all evaluations were conducted under consistent screen conditions (e.g., tension, mesh type, emulsion type, thread count, image) for all screens. In addition, the same technician conducted the evaluations for all product systems at SPTF. The technician at SPTF recorded the following information: amount of product used, time spent on each reclamation step, level of effort required, and a qualitative assessment of product effectiveness and screen condition. (See Appendix L for SPTF methodology.)

Printing Facility Demonstrations

SPAI recruited volunteer screen printers who print on plastic and vinyl substrates from across the country. EPA and SPAI staff matched the submitted product systems to volunteer printing facilities based on existing equipment, ink type, and current practices. Most products were scheduled to be evaluated in two or three facilities to provide performance data from different operating and ambient conditions. Prior to shipping product systems to printers, SPTF repackaged products or removed identifying marks and brand names so that those printers (and the DfE observers) evaluating the products did not know the manufacturer or product name. Masked MSDSs were also developed and shipped along with the product systems to be evaluated.

The appropriate staff at each volunteer facility were asked to:

- provide background information on the facility, its screen printing operations, and its current screen reclamation process and products;

- participate in a one-day site visit in which a DfE observer would observe and document current practices, introduce facility staff to data recording and reporting needs of the project and allow the observation of screen reclamation using the alternative system;

- record information on product performance over a four-week period; and

- participate in a weekly telephone call with the DfE observer.

In designing the protocol and record-keeping, every effort was made to keep volunteer printers' burden low and to minimize production disruptions.

The printers recorded the same performance information as described in the SPTF methodology. Following the receipt of a facility background questionnaire sent by SPAI, the DfE observer called each facility to review the details of their operation and to schedule a site visit. (See Appendix G.) Alternative product systems, MSDSs, application instructions, and spray bottles were shipped to each facility prior to the DfE observer's site visit.

DfE observers were not EPA employees, but were drawn from staff from Abt Associates, Inc., and its subcontractor, Radian Corporation. They conducted the initial site visits to all facilities. During these visits, the observer documented current screen reclamation procedures and the performance of current product systems, as well as three screen reclamations with the alternative system. Printers were asked to comment on the effectiveness of each product (ink remover, emulsion remover and haze remover) and to determine if screen cleanliness was sufficient for future re-imaging and printing. (See Appendix H for an example of the site visit evaluation sheet.) After the observer's visit, the facility continued to use the alternative systems for one month. During this time, facility staff recorded performance information (including subsequent print image quality) on the alternative systems for approximately 12 screen reclamations per week, using the standardized observation forms. (See Appendices I and J for examples of the evaluation sheets for ink removal and for haze and emulsion removal.) Where possible, facilities tracked the screens used in the demonstration to collect information on the long-term performance and effects of these products. Each week, the DfE observer called the facility staff for an update on the product system's performance, as well as to identify any changes in the way the products were used. These calls were documented in telephone logs. (See Appendix K for an example.)

A more detailed explanation of the methodology and product review protocols is provided in Appendix L.

Data Collection

The information summarized in chapters 4 and 5 comes from five sources.

- Each product system was evaluated at SPTF using ink types compatible with the product system (up to three types: solvent-based, UV-cured, and water-based).

- Each facility completed a background questionnaire profiling printing and reclamation operations. The questionnaire was typically either completed or reviewed with the DfE observer during the initial site visit.

- DfE observers visited each facility. During the visits they observed a reclamation with the current product system and up to three reclamations using the alternative system.

- The facility staff completed as many as 12 observation forms per week for four weeks.

- Weekly follow-up calls made by the DfE observers.

Data Summary and Analysis

Summaries and analyses were prepared for each product system keeping each facilities' experiences with that product system separate. A number of statistics correlations were attempted for each facility but the results are typically not statistically significant due to small sample size. Correlations included:

- the effectiveness of ink removal compared with variables, such as, effort/time spent on ink removal, ink color, number of impressions

- the condition of screen after emulsion removal step compared with variables, such as, effort/time spent on emulsion removal, prior ink coverage

- the condition of screen after all reclamation steps are complete (is screen reusable for all types of print jobs) compared with effort/time spent on haze removal, effectiveness of previous steps

Where appropriate, these results are included within the text summaries in Chapter 5 of each product system. Some summary statistics, such as average amount of product used, are presented in accompanying tables.

Limitations

As noted previously, the inclusion of widely variable conditions across and within facilities and the short duration of the performance demonstrations does not allow the results to be interpreted as definitive performance assessments of the product systems. In addition, some facilities did not provide the full complement of observation forms for several reasons including, unacceptable performance of the product system, personnel problems, insufficient volume of products supplied, and lost records of the performance demonstrations.

As mentioned above, the performance demonstrations are not scientifically rigorous but are subjective assessments which reflect the conditions and experience of two to three individual facilities. There are a number of reasons why the results of performance demonstrations for one particular product system may differ from one facility to another and/or from the SPTF results. Among these reasons are:

- Variability of screen conditions. Because performance demonstrations were carried out during production runs, many factors which affect the performance of reclamation products were not controlled during the performance demonstrations including age of screen, ink color, ink coverage, image size, ink type and drying time prior to reclamation.

- Variability of ambient conditions. Conditions, such as temperature and humidity, were recorded but not controlled during performance demonstrations. Many screen printers reported that ambient conditions affect performance of products they use (e.g., temperature effect on drying of ink on screens).

- Chemical interactions with products used previously on screen. Printers and manufacturers have reported that the use of several different types of chemicals previously applied to clean a screen can affect the performance of products currently used to clean the screen. Product systems are often designed for chemical compatibility during the screen reclamation process; if another product is added to the product system that is chemically incompatible, cleaning performance of the system may be affected. This may occur when a particular chemical, such as lacquer thinner, is used to remove ink at press-side during a print run (such as removing ink while the printer stops for lunch); if a printer is using a water-based screen reclamation product system, chemical incompatibilities can affect product system performance. If a printer has been using a variety of hydrocarbon solvents, such as acetone and xylene, to clean a screen, prior to demonstrating the effectiveness of an alternative system, the performance of the alternative system may be affected by a residue of hydrocarbons on the surface of the screen. In the second case, the testing would be more effective if a new screen was used; however, this was typically not the case in the performance demonstration. In either case, the performance demonstration may have been affected by (1) residue chemicals on the surface of the screen or (2) the chemical "conditioning" of the screen.

- Variability of staff involved in performance demonstrations. At SPTF, the same technician conducted and recorded all testing. At the volunteer facilities, more than one individual often conducted the reclamations during which data were collected. Reclaimers' past experience also differs and can affect their perception of performance. For example, a screen reclaimer who has only used highly effective ink removers may differ in their opinion of "moderate scrubbing effort" from a reclaimer whose current ink remover instructions call for one to two minutes of scrubbing with a brush.

Product System Summaries

A performance summary of each product system is detailed in Chapter 5. In each is a general summary of product performance, a description of the product application method, results from the evaluation at SPTF, details of product performance reported separately for each volunteer printing facility, and facility background information. For each product system, a table is also included which provides certain summary statistics from the performance demonstrations at the volunteer printing facilities and at SPTF (for three ink types). For a quick summary of the results, the table providing summary statistics is very helpful.

Chemical Volume Estimates

Volumes for chemicals used within screen reclamation were estimated. Volumes of the chemicals produced within the nation, export volumes, and import volumes were estimated from information obtained from the following sources: Chemical Economics Handbook[5], US ITC[6], Mansville[7], US EPA reports[8], Kirk-Othmer[9], and industry sources. In some cases, volumes reported represent broader categories than the individual chemical. Volumes for the portion of the chemicals used within screen reclamation was not readily available.

The Workplace Practices Questionnaire,[10] SPAI's 1990 Survey,[11] and expert opinion estimates were used to develop an estimate of the chemical volumes. The following methodology summarizes the assumptions and calculations used to estimate the annual national totals of chemicals used in screen reclamation.

The information needed to develop the estimates included the average screen size, the per screen volume of each type of reclamation product, market shares, the number of screens cleaned yearly, and the number of screen printing operations. This information, and its sources, is summarized in Table III-1.

The screen size, in conjunction with the amount of product used or purchased and the number of screens cleaned, was used to determine the per screen product usage. Typical formulations were then used to determine the chemical breakdown of the reclamation products. Combining this information resulted in estimates of the volumes of chemicals used for screen reclamation. Additional detail of the methodology is given below.

Average Screen Size

Estimated from the Workplace Practices survey, observations were weighted by the number of screens cleaned per day. This is a normalization technique which incorporates the frequency of screen cleaning as well as the size of the screens. The average screen size was

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[5]SRI. selected reports from 1985 to 1993. Chemical Economics Handbook. SRI International, Menlo Park, CA.

[6]USITC. 1993 and 1994 Synthetic Organic Chemicals: United States Production and Sales, 1991, U.S. International Trade Commission, Washington, DC.

[7]Manville. selected reports from 1990 - 1993. Manville Chemical Products Corporation, Asbury Park, NJ.

[8]US EPA reports, including the Toxic Substances Control Act Chemical Substance Inventory (1985), "Aqueous and Terpene Cleaning" (1990), "Economic Analysis of Final Test Rules for DGBE and DGBA" (1987), "Glycol Ethers: An Overview" (1985)

[9]Kirk-Othmer, 1981, "Oils,essential." Om: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed., vol 16. New York: Wiley.

[10]The Workplace Practices Questionnaire was developed by EPA, SPAI and the University of Tennessee in 1993. It contains information on 115 screen printing facilities' operating and work practice characteristics. See Appendix B for a reproduction of the blank questionnaire and Appendix C for a summary of responses.

[11]Screen Printing Association International, *1990 Industry Profile Study*, (Fairfax, Va.: 1991).

estimated to be 2,916 square inches. This value differs from the average in the appendix due to this normalization to incorporate incomplete responses.

Per Screen Product Usage

Usage levels for three types of reclamation products were calculated using information collected through the Workplace Practices Survey: ink remover, emulsion remover, and haze remover. Information used included average screens printed per day, volumes of products purchased each year, and the unit price of the products. Certain observations such as those from facilities carrying out in-plant recycling, were excluded from the calculations as these would distort the average volume used per screen of one-time ink removal operations. The average volume used per screen was calculated by dividing the annual amount of product purchased by the number of screens cleaned per year (assuming 252 working days and the midpoint of the range of screens cleaned per day).

Derivation of Market Share of Traditional and Alternative Screen Reclamation Products

Current use of screen reclamation products is divided between *traditional* products, generally high VOC solvents, and *alternative* products, usually low or no VOC content products. To calculate the market share represented by each type of product, data was collected from the Work Practices Survey (see Appendices B and C). In the calculation, market share is not based on volume used but rather on total screen area cleaned since traditional and alternative products may require very different quantities to clean the same screen area.

The formula used to calculate market share is as follows:

$$\text{Market Share}_{Alt} = A_{Alt}/A_{Alt+Tra} \qquad \text{Market Share}_{Tra} = A_{Tra}/A_{Alt+Tra}$$

Where:

$_{Alt}$ denotes Alternative Product
$_{Tra}$ denotes Traditional Product

$$A = \text{total screen area cleaned daily} = \sum_{n}^{F} [\text{\# of screens cleaned daily x area of screens}]$$

F = number of facilities cleaning screens

Ink Removers

A simplistic decision rule, based on expert opinion, was used to classify ink removers as alternative or traditional. If the price of an ink remover in the Work Practices Survey was below $5.60/gallon then it was considered traditional. If the unit price was above $18.90/gallon then the product was considered to be alternative. An additional seven ink removal products were assigned as traditional or alternative based on having a brand name in common with a product assigned using the price thresholds.[12] As the Work Practices Survey collected brand names, we did not know the composition of the product and had no other method to determine which category the products fit into. Once facilities were identified as using either traditional or alternative products, the screen area cleaned per day for each facility was estimated.[13] The screen area cleaned per day is then summed across facilities within product types. To estimate market share, the screen area cleaned using each type of product was then divided by the total screen area cleaned daily with both types of products. The results indicate that the percentage of total screen area cleaned using traditional products equals 65.6% and the percentage of total screen area cleaned using alternative products equals 34.4%.

Emulsion Removers

As there is little difference among emulsion removers used in the Work Practices survey no distinction was made between traditional and alternative emulsion removers.

Haze Removers

The market share of haze removers used by printing operations that is considered to be traditional and the market share that is considered to be alternative is not known. Consequently, in the cost analysis, it was assumed that all haze removers currently used are traditional products.

Number of Screens Cleaned

The number of screens cleaned per year was taken from SPAI's 1990 survey, where facilities reported which range they fit into. In order to use this information for our calculations, an average value was chosen to represent each range. For the top range of 41 screens or more, 50 screens per day was used. The remaining figures are reported in Table III-1.

Using an SPAI estimate of 20,000 screen printing facilities (excluding textile printers), the total number of screens cleaned per day can be estimated. For example, 57 percent of facilities clean one to ten screens, or an average of 5.5, a day, resulting in 62,700 screens a day for that particular range. Continuing the analysis results in an estimate of 272,710 screens cleaned per day.

[12] A substantial portion (~ 70%) of screen area reported in the Work Practices survey could not be assigned to traditional or alternative products and were, therefore, not included in the above calculation.

[13] Data reported in the Work Practices Survey was limited to the total volume of alternative and traditional products purchased annually and the total number of screens cleaned per day at the facility. The number of screens cleaned per day with each type of product was not indicated. As a result, the average price of the ink remover was calculated and used to establish which type of product the facility was using.

Table III-2
Information for Screen Reclamation
Chemical Volume Estimates

Description	Data		
Average screen size[a]	2916 sq in		
Per screen product usage[a]	Product	Oz/Screen (Gal/Screen)	
	Ink remover (traditional)	98 (0.7663)	
	Ink remover (alternative)	22 (0.1731)	
	Emulsion remover	8.8 (0.0685)	
	Haze remover	2 (0.0160)	
Ink remover market share[a,d]	Traditional - 65.6% Alternative - 34.4%		
Screens cleaned per day[b]	Range of # of Screens	Value used	% of facilities
	1 to 10	5.5	57.0
	11 to 20	15.5	23.2
	21 to 30	25.5	9.8
	31 to 40	35.5	4.1
	41 or more	50	5.9
Number of screen printing facilities[c]	20,000		
Number of screens cleaned per day[d]	272,710		

[a]Based on raw data from WPQ for screen printing adjusted for incomplete responses.
[b]SPAI's 1990 Industry Profile.
[c]SPAI estimate.
[d]Calculated value.

National Estimates of Screen Reclamation Products

Multiplying product usage per screen by market share by the total number of screens cleaned per year provides estimates of the amount of screen reclamation products used nationally. All facilities are assumed to use ink remover, emulsion remover, and haze remover; this may result in an overestimate of chemicals used as not all facilities use haze remover, at least not on all screens. Market share estimates, developed by EPA in consultation with industry experts, are provided in Table III-3.

Table III-3
Estimated Market Share for Screen Reclamation Products

Chemical	Market Share (%)
Ink Remover, Traditional Formulations	
Xylene	20
Mineral spirits	20
Acetone	20
Lacquer thinner[a]	40
Ink Remover, Alternative Formulations	
Propylene glycol methyl ether	10
Methoxypropanol acetate	10
Dibasic esters[b]	30
Diethylene glycol	3
Propylene glycol methyl ether acetate	5
Terpineols/d-limonene (50/50)	7
Propylene glycol	5
Tripropylene glycol methyl ether	15
Diethylene glycol butyl ether	10
Cyclohexanone	5
Emulsion Remover	
Bleach (sodium hypochlorite) (12% solution in water)	10
Sodium metaperiodate (4% solution in water)	80
Periodic acid (10% solution in water)	5
Sodium bisulfate (50% solution in water)	5
Haze Remover	
Sodium hydroxide (20% solution in water)	25
Potassium hydroxide (20% solution in water)	25
Sodium hypochlorite (12% solution in water)	10
Mixture of 65% Glycol ethers[c] and 35% N-methylpyrrolidone	10

Table III-3
Estimated Market Share for Screen Reclamation Products

Chemical	Market Share (%)
Mixture of 10% d-limonene, 20% Sodium hydroxide, and 70% water	10
Mixture of 10% Xylene, 30% Acetone, 30% Mineral spirits, and 30% Cyclohexanone	20

[a]The formulation for Lacquer thinner is as follows:

	CAS #	Percentage
(1) Methyl ethyl ketone	78933	30%
(2) n-butyl acetate	123-86-4	15%
(3) Methanol	67561	5%
(4) Solvent naphtha, light aliphatic	64742-89-8	20%
(5) Toluene	108883	20%
(6) Isobutyl isobutyrate	97858	10%

[b]This category includes dimethyl glutarate, dimethyl adipate, dimethyl succinate in a 2:1:1 ratio.

[c]This category includes propylene glycol methy ether, methoxypropanol acetate, propylene glycol methyl ether acetate, tripropylene glycol methyl ether, and diethylene glycol mono butyl ether in equal portions.

Estimates of Chemical Usage for Screen Reclamation

To estimate the amount of individual chemicals used, the product volumes estimated earlier were combined with the market share estimates to determine the amount of individual chemicals used. Chemicals that are solids at room temperature are reported in units of mass (pounds) and those that are liquids are reported in units of volume (gallons). The estimated amount of chemicals is reported in Table III-4. Many of the chemicals do not have estimates; the chemical's specific information provided for this analysis (reported in Table III-2) is an overview and, therefore, did not cover all of the chemicals used in screen reclamation. We were unable to collect volume information directly from reclamation product manufacturers.

Table III-4
Estimated Annual Amount of Chemicals Currently Used in Screen Reclamation
(Liquids are reported by volume, solids by weight)

Chemical	Volume (Gallons)	Weight (Pounds)
Acetone	6,920,000	
Alcohols, C8-C10, ethoxylated	NA[a]	NA
Alcohols, C12-C14, ethoxylated	NA	NA
Benzyl alcohol	NA	NA
2-Butoxyethanol	NA	NA
n-Butyl acetate	1,920,000	
Butyrolactone	NA	NA
Cyclohexanol	NA	NA
Cyclohexanone	270,000	
Diacetone alcohol	NA	NA
Dichloromethane	NA	NA
Diethyl adipate	NA	NA
Diethyl glutarate	NA	NA
Diethylene glycol	122,000	
Diethylene glycol monobutyl ether	420,000	NA
Diethylene glycol butyl ether acetate	NA	NA
Diisopropyl adipate	NA	NA
Dimethyl adipate		2,700,000
Dimethyl glutarate	609,000	5,500,000
Dimethyl succinate	304,000	
Dipropylene glycol methyl ether	NA	NA
Dipropylene glycol methyl ether acetate	NA	NA
Dodecyl benzene sulfonic acid, triethanol amine salt	NA	NA
Ethoxylated castor oil	NA	NA
Ethoxylated nonylphenol	NA	NA
Ethyl acetate	NA	NA
Ethyl lactate	NA	NA

Table III-4
Estimated Annual Amount of Chemicals Currently Used in Screen Reclamation
(Liquids are reported by volume, solids by weight)

Chemical	Volume (Gallons)	Weight (Pounds)
Ethyl oleate	NA	NA
Fumed silica	NA	NA
Furfuryl alcohol	NA	NA
Isobutyl isobutyrate	2,630,000	
Isobutyl oleate	NA	NA
Isopropanol	NA	NA
d-Limonene		1,100,000
Methoxypropanol acetate	420,000	
Methanol	610,000	
Methyl ethyl ketone	3,720,000	
Methyl lactate	NA	NA
Mineral Spirits	6,920,000	
N-Methyl pyrrolidone	38,000	
2-Octdecanamine, N,Ndimethyl, Noxide	NA	NA
Periodic acid		1,020,000
Phosphoric acid, mixed ester w/isopropanol and ethoxylated tridecanol	NA	NA
Potassium hydroxide		1,060,000
Propylene carbonate	NA	NA
Propylene glycol	203,000	
Propylene glycol methyl ether	418,000	
Propylene gycol methyl ether acetate	217,000	
Silica	NA	NA
Silica, fumed (amorphous, crystalline-free)	NA	NA
Sodium bisulfate		2,350,000
Sodium hexametaphosphate	NA	NA
Sodium hydroxide		1,450,000
Sodium hypochlorite	69,000	

Table III-4
Estimated Annual Amount of Chemicals Currently Used in Screen Reclamation
(Liquids are reported by volume, solids by weight)

Chemical	Volume (Gallons)	Weight (Pounds)
Sodium lauryl sulfate	NA	NA
Sodium metasilicate	NA	NA
Sodium periodate		11,700,000
Sodium salt, dodecylbenzene sulfonic acid	NA	NA
Solvent naphtha, heavy aromatic	NA	NA
Solvent naphtha, light aliphatic	2,160,000	
Solvent naphtha, light aromatic	NA	NA
Special tall oil	NA	NA
Terpineols		1,100,000
Tetrahydrofurfuryl alcohol	NA	NA
Toluene	2,670,000	
1,1,1-Trichloroethane	NA	NA
1,2,4-Trimethylbenzene	NA	NA
Triethanolamine salt, dodecyl benzene sulfonic acid	NA	NA
Tripropylene glycol methyl ether	623,000	
Trisodium phosphate	NA	NA
Xylene	6,880,000	

[a]Not available. Some chemical amounts were not estimated; sufficient information on the use of those chemicals in the screen printing industry was not available.

Cost Analysis Methodology

The following methodology was used to estimate the costs of baseline screen reclamation as well as the cost of six alternative chemical, technological and work practice substitutes. The cost estimation methodology is intended to reflect standard industry practices and representative data for the given screen reclamation substitutes. The performance demonstrations conducted during production runs at 23 volunteer facilities in early 1994 were the predominant source of information for the cost estimates. Information from the performance demonstrations was supplemented by several other sources, including (1) product evaluations undertaken by the Screen Printing Technical Foundation (SPTF), (2) equipment specifications from manufacturers and distributors, (3) industry statistics collected by trade groups, (4) EPA's risk assessment work undertaken as part of the CTSA, and (5) industry experts and suppliers.

For each substitute method, annual facility costs and per screen costs were estimated for individual facilities (those involved in the performance demonstrations) whose operations were characteristic of the given substitute method. For the hypothetical baseline facility, the total annual cost and per screen cost were estimated for reclaiming six screens (2,127 in^2) per day. In addition, each facility's costs were normalized to allow cross-facility comparisons, particularly with the baseline scenario. Normalized values adjust product usage, number of screens cleaned, and number of rags laundered at demonstration facilities to reflect the screen size and number of screens cleaned per day under the baseline scenario.

A general description of the cost estimation methodology and data sources used is presented below. The second section presents additional details for the baseline scenario and each of the six substitute screen reclamation methods.

General Description of Costing Methodology

The baseline screen reclamation scenario and substitutes are defined as follows:

- Baseline. Traditional chemical formulations for ink removal, emulsion removal and haze removal.
- Method 1. Chemical substitutes for ink removal and emulsion removal. No haze removal required.
- Method 2. Chemical substitutes for ink removal, emulsion removal and haze removal.
- Method 3. SPAI Workshop Process -- Chemical substitutes for ink removal, ink degradant, degreasing and emulsion removal. No haze removal required.
- Method 4. Technology substitute of high pressure wash for ink removal; technology substitute and reclamation products used for emulsion and haze removal.
- Technology substitute. Use of automatic screen washer for ink removal.
- Work practice substitute. Screen disposal in lieu of reclamation.

In general, the cost estimate for each reclamation method was composed of the sum of six distinct cost elements: labor, reclamation products, materials, resource use, equipment, and waste disposal.

- Labor. The printer's staff time spent on each reclamation step (e.g., ink removal, emulsion removal, haze removal and degreasing) was collected or estimated from various sources. The total time estimate does not include collecting screens from printing areas, waiting for product reactions as might be specified in the manufacturers's application instructions, maintenance of reclamation area, or handling of segregated waste materials. The labor cost was calculated as the total time spent multiplied by (1) the average wage rate for screen reclaimers of $6.53/hour (as reported in SPAI's *1993 Wage Survey Report for the Screen Printing Industry*) and (2) an industry multiplier of 2.01 (calculated from SPAI's *1992 Operating Ratios Study*) to account for fringe and overhead costs.

○ Reclamation products. The average usage per screen was calculated for each product (i.e., ink remover, emulsion remover, haze remover, and degreaser) used by a particular facility. Because of wide variations, no attempt was made to average across facilities or product systems within the same substitute method. For comparative purposes, "normalized" average quantities were calculated by multiplying actual usage with the ratio of the baseline screen size of 2,127 in^2 to the recorded screen size. Multiplying usage with the unit cost of each product (provided by each participating manufacturer and summarized in Table III-5) yielded the reclamation product costs. Costs associated with special storage requirements for products were not considered in the cost analysis.

Table III-5
Alternative Screen Printing Systems: Manufacturer Pricing

System	Ink Remover	Emulsion Remover	Haze Remover
Alpha	$18.18/gallon (5 gallons/$91) (55 gallons/$850)	$4.00/gallon	$9.39/gallon (5 kg/$50)
Beta	$15.10/gallon	Ink remover only	Ink remover only
Chi	$31.20/gallon (5 gallons/$156) (55 gallons/$1,315)	$32.00/gallon (5 gallons/$160) (15 gallons/$438) (55 gallons/$1,238)	$31.20/gallon (5 gallons/$156) (55 gallons/$1,315)
Delta	$20.00/gallon (5 gallons/$100) (55 gallons/$900)	$32.00/gallon (5 gallons/$160) (15 gallons/$438) (55 gallons/$1,238)	$20.00/gallon (5 gallons/$100) (55 gallons/$900)
Epsilon	$7.80/gallon (5 gallons/$39)	$13.54/gallon (5 kg/$149)	$1.09/gallon (15 kg/$36)
Gamma	$10.90/gallon (25 liters/$72) (5 gallons/$55)	$1.60/lb (15 kg/$53)	$9.39/gallon (25 liters/$62) (5 gallons/$52)
Mu	($7.76/gallon) (20 liters/$41) (5 gallons/$39)	$10.34/gallon (3 five liter units/$41) (5 gallons/$52)	$7.57/gallon (5 five liter units/$50) (5 gallons/$189)
Phi	$24.95/gallon	$24.95/gallon	$39.95/gallon
Omicron	$13.40/gallon (5 gallons/$67) (55 gallons/$540)	$11.00/gallon (5 gallons/$55) (55 gallons/$530)	$18.00/gallon (5 gallons/$90)
Theta	No ink remover costs Other costs: $5,170	$21.95/gallon	$43.00/gallon

Table III-5
Alternative Screen Printing Systems: Manufacturer Pricing

System	Ink Remover	Emulsion Remover	Haze Remover
Zeta	$23.00/gallon	$23.00/gallon	$30.00/gallon

Note: Volume conversions were made using 3.785 liters/gallon.
The price of the greatest volume in the table (e.g., 55 gallons) was used when estimating cost for a particular system.

- Materials (e.g., rags, screens). This element is most important for the work practice substitute of screen disposal. A supplier quote was used for the unit cost of screen mesh (40" wide, 260 threads per square inch). Wastage was assumed to be 10 percent of the screen size. For all methods, rag use was estimated or recorded for the baseline and all substitute methods. It was assumed that rags were leased and laundered at a cost of $0.15/rag. Changes in the number of application brushes between the baseline and substitute methods is considered inconsequential.

- Resource Use. The cost of electricity and water was addressed quantitatively only for Method 4 (high pressure wash). The equipment was assumed to be in operation only for the recorded time spent on ink removal. Equipment specifications for flow rate and electrical rating provided by the manufacturer allow the calculation of water and electricity use. The cost of water, electricity and sewer were estimated using utility rates in the Northeast, a generally conservative assumption. For all other methods, changes in resource use are considered inconsequential.

- Equipment. Equipment costs were considered for Method 4 (high pressure wash) and the automatic screen washer only. Equipment costs common to all the methods and the baseline were excluded from the analysis. The capital costs were amortized over a ten-year period, the estimated engineering life of the equipment. An interest rate of 7 percent for small business loans was used (which represents the marginal rate of return on capital). The annualized cost of equipment was adjusted (using a marginal tax rate of 34 percent) to reflect the nontaxable nature of interest and (10-year) depreciation for such equipment.

- Waste disposal. Hazardous waste disposal costs were assumed only if the reclamation products contain RCRA-listed chemicals or if the products are defined as characteristic wastes due to their ignitable nature (See Table III-6). For each product system, hazardous waste generation rates (in g/day for 6 screens), were estimated by chemical engineers on EPA's staff. This methodology does not consider the possible effect residual inks may have on the waste's hazard classification. It also assumes that other wastestreams at the facility are hazardous; thus, the labor cost of training and managing hazardous wastes is not associated with screen reclamation only. Given that filtration systems used to remove residual inks and reclamation products from spent wash water (spent filters must be disposed of) may be required for both baseline and alternative systems, filtration system and filter disposal costs were not included in the cost analysis. The analysis focuses on quantifying cost differences among reclamation methods.

Table III-6
Alternative Screen Printing Systems: Determination of RCRA Hazardous Waste Listing

System	Ink remover	Emulsion remover	Haze remover
Alpha	RCRA Characteristic waste (ignitable) Flashpoint = 101°F/38°C	None	None
Beta	None	Ink remover only	Ink remover only
Chi	None	None	None
Delta	None	None	None
Epsilon	RCRA Listed waste (cyclohexanone - all other components qualify as listed under mixture rule). Also Characteristic waste (ignitable) Flashpoint = 46°C/115°F	None	1:1 dilution with ink remover. All components quality as hazardous waste under mixture rule.
Gamma	None	None	None
Mu	RCRA Characteristic waste (ignitable) Flashpoint = 131°F/55°C	None	None
Phi	None	None	None
Omicron (AE & AF)	None	None	None
Theta	No ink remover	None	RCRA Listed waste (cyclohexanone - all other components qualify as listed under mixture rule)
Zeta	RCRA Characteristic waste (ignitable) Flashpoint = 101°F/38°C	None	None

All information on flashpoint was gathered from masked MSDSs submitted by supplier. None of the above information should be used for compliance purposes. None of the chemicals in these formulations is listed as toxic characteristic contaminants and were not treated as such in the cost analysis; however, printers should use the Toxicity Characteristic Leaching Procedure (TCLP) to determine the applicability of the toxicity characteristic to their particular waste stream.

Details Related to Data Sources and Methodological Approach

In addition to the methodological approach outlined above, there a number of important assumptions and differences specific to the cost estimations of each screen reclamation method. Details related to data sources and the methodological approach used to estimate the cost of each reclamation method are presented below.

Baseline Screen Reclamation

Four traditional systems are defined in Chapter 5, the primary distinction among them being the chemical constituents of the ink remover, emulsion remover and haze remover. Traditional System #4 was used to estimate baseline costs, as it was expected to be more representative of systems currently in use. The baseline products used are described as follows:

Ink remover	=	lacquer thinner
Emulsion remover	=	1.25% sodium periodate in water
Haze remover	=	10% xylene (by weight) 30% acetone

30% mineral spirits
30% cyclohexanone

For ink remover, time and volume information was taken from SPTF testing. An average price for lacquer thinner was calculated from prices reported in the Workplace Practices Questionnaire conducted by SPAI and the University of Tennessee. Time, volume, and price information for baseline emulsion removal was taken from the Zeta system used in performance demonstrations. Time and volume information for the four-chemical baseline haze remover was not available from the performance demonstrations and had to be estimated based on the SPTF evaluation of a similar haze remover, resulting in a time of 11.5 minutes. A volume of 3 ounces for haze removal was taken from the application instructions developed for SPTF. A price for purchasing this formulation in a 55-gallon drum quantity was quoted by Ashland Chemical.

A second baseline scenario was developed which excluded the haze removal step. The second baseline reflects the fact that between 27 and 80 percent of facilities regularly use a haze remover. The second baseline also allowed comparisons of Method 1 (no haze removal) with a similar baseline.

Substitute Method 1: Chemical Substitutes for Ink Removal and Emulsion Removal. No Haze Removal Required.

Two assumptions affect the cost analysis of Substitute Method 1. Eliminating haze removal avoids both the material and labor costs of haze removal. The estimated cost difference between Substitute Method 1 and the baseline may also be affected by the assumption that the baseline facility uses haze remover during all screen reclamations; however, industry figures indicate that haze removal is undertaken on between 27 and 80 percent of reclamations. Therefore, the baseline used in the analysis of this alternative method excludes haze removal. The amount of ink remover and emulsion remover used and time spent on reclamation were taken from performance demonstrations. Product prices were provided by participating suppliers. Performance demonstration results from product systems Chi (excluding the haze removal step) and Beta (including an emulsion removal step from System Zeta) were used to estimate the cost of Substitute Method 1.

Substitute Method 2: Chemical substitutes for ink removal, emulsion removal and haze removal.

The amount of each reclamation product used and time spent on reclamation were available from the performance demonstrations. Product prices were provided by participating suppliers. Performance demonstration results for product systems Alpha, Chi, Delta, Epsilon, Gamma, Mu, Phi, Omicron-AE, Omicron-AF, and Zeta were used to estimate the cost of Substitute Method 2.

Substitute Method 3: SPAI Workshop Process -- Chemical substitutes for ink removal, ink degradant, degreasing and emulsion removal. No haze removal required.

The amounts of ink and emulsion removers used were available from performance demonstrations of product system Omicron. Based on information about the SPAI Workshop Process, which indicated that the overall time spent reclaiming screens would not change appreciably from a typical reclamation process, the average time spent (including 5 minutes for treatment with ink degradant and degreasing) from the evaluation of product system Omicron by four facilities was used to estimate labor costs. Documentation of the SPAI Workshop Process was used to estimate the amount of ink degradant (3 ounces) and degreaser (3 ounces) used. Product prices were available from participating suppliers.

Substitute Method 4: Technology substitute of high pressure wash for ink removal; technology substitute and reclamation products used for emulsion and haze removal.

Data collected by SPTF staff during a facility visit and equipment specifications provided by the manufacturer were used to develop the cost for this method. The capital cost of this equipment was annualized by the method described above and added to the recurring operating and maintenance costs and divided by the number of screens reclaimed per year to arrive at the per screen equipment costs. Water, wastewater and electrical usage costs were included in the cost estimate for this method only. As in all other cost estimations, the cost of a filtration system was not included as the analysis was focused on quantifying cost differences between reclamation systems, without accounting for filtration costs that could be expected to occur in all cases.

Technology Substitute of Automatic Screen Washer for Ink Removal

Although several suppliers of automatic screen washers were asked to participate in performance demonstrations, none accepted. As information on automatic screen washers was, therefore, not collected as part of the performance demonstrations, it was gathered from other sources, including an equipment supplier and a printer. Two cost estimates were developed which reflect the baseline facility's operations and size and the range of equipment available. Typically, automatic screen washers substitute for the ink removal step; emulsion removal and haze removal may still be required.

Automatic Screen Washer #1 was a large capacity (in terms of the maximum size of screen) enclosed washer with a fully automated feed system to move the screens through separate wash and rinse areas. It was assumed that mineral spirits were in both reservoirs. As mineral spirits were used in the ink removal step, the cost analysis of automatic screen washer #1 assumes the same emulsion and haze removal costs as in the baseline. Its purchase price was assumed to be $95,000, the original manufacturer's list price, although the printer purchased the equipment at auction. The only operating costs were related to solvent make-up (daily) and replacement of the reservoirs' contents 70 gallons (every eight to nine months). Information on other operating costs was not available; it was assumed that these costs would be minimal as compared to the equipment costs. Time spent loading and unloading the washers was taken from manufacturer's documentation of the equipment. As the equipment's electrical rating was not available from information provided by the distributor, electrical costs were not included. The price of mineral spirits ($4.00/gallon) was taken from the Work Practice Survey. Emulsion removal and haze removal costs were assumed to be similar to those of the baseline system.

Automatic Screen Washer #2 is a smaller unit. Screens must be loaded and unloaded by hand. Because it uses a solvent with lower volatile fraction than #1, more solvent remains on the screen and must be washed off following ink removal. Time spent loading and unloading the washers was taken from manufacturer's documentation of the equipment. Two pumps operate using compressed air which is reportedly available from other sources at the facility; the cost of a generator was not included in the cost analysis. The price of the ink remover was provided by the equipment supplier. Emulsion removal costs were assumed to be similar to those of the baseline system. The manufacturer indicated that a haze remover was not required given the formulation of the ink remover.

Work Practice Substitute of Screen Disposal

The cost estimate of screen disposal was developed for comparison to other reclamation methods. Information on screen disposal was not collected as part of the performance demonstrations. Consequently, one cost estimate was developed which reflects the baseline facility's operations and size. It should be noted that screen disposal is most cost effective under two circumstances not assumed for the model facility's operations: where production runs approach the useful life of a screen and where the size of the screen is relatively small. A number of assumptions were used to estimate the cost of this substitute method, including:

- No other changes in operations or equipment were required.
- Waste screens do not need to be handled as hazardous waste under RCRA which would greatly increase the estimated cost.

- The replacement of screens (after reaching the end of the useful life of the mesh) was not considered in the baseline nor in any of the other reclamation methods; it is estimated to be approximately $0.60/screen reclaimed. Consequently, this value was deducted from the total cost of this method.

- The average wage rate of screen stretchers ($6.87), which is slightly higher than for screen reclaimers, was used to calculate labor costs for this method.